Bubbles in Sediments

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LONG-TERM GOAL

This research investigates the scattering of an acoustic field from bubbles embedded in a fluid saturated sediment. The primary objective is the establishment of underlying physical mechanisms for resonance scattering near the monopole resonance.

OBJECTIVES

Bubbles are known to be present in naturally occurring sediments particularly in littoral regions, and it has been proposed that these bubbles are primary contributors to volume scattering of sediment penetrating sonars.

APPROACH

The monopole resonance scattering from an isolated bubble in an infinite, isotropic, homogeneous sediment was analyzed where the sediment is modeled as either an effective fluid medium, an effective viscoelastic solid, or a fluid saturated poroelastic medium. The analysis includes a frequency range that encompassed the frequency associated with the monopole resonance. This resonance dominates the dynamics of a bubble even within the linear approximations used throughout this analysis for the bubble motion. The complexity of wave propagation in the choice of model for a sediment increases from a fluid model (simplest) to a fluid saturated poroelastic model (most complex).

Based on the results of the theoretical treatment, a laboratory experiment has been designed to test which model provides a suitable characterization of the underlying wave propagation and scattering phenomenon. The experiment embeds a bubble in a synthetic, transparent sediment. This sediment is prepared by matching the optical indices of refraction of glass beads and a saturating fluid. The forward extinction of a helium-neon laser by an acoustically driven bubble is characterized by a modulation of the optical intensity. The frequency of modulation is directly related to the dynamics of the bubble.[1]

A second experiment has been planned which eliminates the acoustic driving field. This reduces the reverberation due to the finite volume of artificial sediment and the container. Additionally, the need for a transparent sediment has been removed because the bubble dynamics can be monitored via a hydrophone embedded within the sediment. The bubble is forced into its monopole resonance through an imposed electric field with an appropriate frequency. Dielectrophoretic forces at the surface of the bubble cause it to oscillate at the frequency of the electric field with a maximum response at the frequency of the monopole resonance of the bubble [2].

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WORK COMPLETED

The theoretical treatment of the monopole response of an isolated bubble in a fluid saturated poroelastic has been completed and documented[3]. This work is currently being extended to multiple bubbles where multiple scattering affects are important. To facilitate a comparison between scattering in a fluid, viscoelastic, and poroelastic medium, consistent governing equations have been derived. This includes the underlying physical assumptions needed to derive wave equations and stress tensors as well as effective medium theories to approximate required material parameters. A technical report describing these results is currently under preparation [4]

Experimental verification of theoretical predictions has progressed to the measurement of the optical extinction. A synthetic transparent sediment has been constructed from nominally 300 micron glass beads obtained from Cataphote Inc. The beads are saturated with immersion liquid code 1160 from Cargille Laboratories Inc. Although the saturated beads are not perfectly clear to white light, an embedded bubble is visible and the principal laser line from a HeNe laser (632.8 nm) passes through a small volume without much loss. The experiment is scheduled to be completed in early FY98.

The soda-lime beads available from Cataphote Inc. contained a large amount of impurities. These impurities included debris on and embedded within the beads, gas bubbles within beads, surface pits, and irregular jagged pieces. A cleaning procedure was developed to reduce these impurities. First, the beads were separated from jagged shards by pouring the beads on a slightly inclined surface with a Teflon coating. This produced a rapid removal of the shards which significantly affect the light transmission of a prepared transparent sediment. The glass beads were then poured down a paper-lined surface where the remaining shards are trapped by the texture of the paper. Discolored beads and beads with interior imperfections were then removed via a miniature vacuum system. Finally, the surfaces of the remaining beads were polished in concentrated acid baths. The acids used were nitric acid as well as hydrofluoric acid.

RESULTS

If a sediment can be characterized by an effective fluid model, then theory predicts a bubble will support a breathing mode resonance on the order of a few kHz in agreement with the well-known Minnaert resonance frequency. The viscoelastic solid model for a sediment predicts a much higher resonance frequency due primarily to the inclusion of shear rigidity in the model. It is noted that both an effective fluid model and an effective viscoelastic solid model predict a single breathing mode resonance, and the frequency of this resonance are widely separated for each model. Finally, if a sediment is modeled by Biot theory, which describes wave propagation in a saturated poroelastic medium, then two monopole resonances are predicted. These resonances appear to be an intrinsic property of Biot theory, and hence, can validate the application of Biot theory to sediment acoustics. The predicted resonance behavior under each model is distinct, so an optical extinction measurement may provide an unambiguous measure of which model(s) applies.

IMPACT/APPLICATION

Bubbles are known to occur in natural sediments. It is expected that the knowledge gained in this research will impact sediment penetrating sonar systems used in mine countermeasure operations and the interpretation of images produced by these system.

TRANSITIONS

The present research will be extended from single isolated bubbles to multiple bubbles where multiple scattering becomes important. Additionally, the infinite medium assumption imposed to isolate the resonance behavior will be removed such that the bubble will be embedded in a plane stratified medium of arbitrary composition. These extensions are expected to transition into enhancement to sonar prediction tools such as the Shallow Water Acoustic Toolset (SWAT) available from the Coastal Systems Station, Dahlgren Division, Naval Surface Warfare Center.

RELATED PROJECTS

The current research has a potential impact on the Departmental Research Initiative (DRI) entitled "High-Frequency Sound Interaction in Ocean Sediments" under the sponsorship of ONR Code 321 Ocean Acoustics. The DRI is addressing the subcritical penetration of a sonar signal into sediments. One hypothesis for this penetration is the interaction of volume inhomogeneities with the evanescent field near the sediment-water interface.

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[3] S.G. Kargl, K.L. Williams, and R. Lim, "Double monopole resonance of a gas-filled, spherical cavity in a sediment," *J. Acoust. Soc. Am.*, **103**, 265-274 (1998)

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PUBLICATIONS

[1] S.G. Kargl, K.L. Williams, and R. Lim, "Double monopole resonance of a gas-filled, spherical cavity in a sediment," *J. Acoust. Soc. Am.*, **103**, 265-274 (1998)